Electromagnetic Fields and Health Report

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Summary: After reviewing the properties of natural and artificial electromagnetic fields, some aspects of the interaction between electromagnetic fields and biological tissues are analyzed, giving preferential attention to the problem of cancer. Then some guidelines and reviews that introduce thresholds to electromagnetic exposure of human beings are critically analyzed.

Key words: Electromagnetic fields. Interaction of electric, magnetic, and electromagnetic fields with biological tissues. Electromagnetic fields and cancer, Umwelt, Mitwelt, Eigenwelt.

(1) Introduction

The emphasis in this report, aimed mainly at a public with a background in mathematics, physics and general biology at college level, is on possible biological effects associated with microwave and radio wave fields. Some more demanding topics appear during the development of this subject, but either they are explained in certain detail or references are given to ease further study.

Let us briefly review, to begin with, some of the properties of the electromagnetic field that must be considered when studying their interaction with living things.

Electric charges originate electric fields, and moving electric charges originate magnetic fields. While electric field lines begin and end in electrical charges, magnetic field lines surround currents. Accelerated charges generate electromagnetic radiation in which the electric and magnetic fields are interrelated, and the lines of both fields close in on themselves in regions of space far from the field's sources.

In general, electromagnetic sources produce both radiant energy (radiation or far fields) and non-radiant energy (near fields).

For a system in which variable electric currents have been installed to behave like an antenna, that is, an efficient source of radiation, it must have a length comparable to the wavelengths corresponding to the frequencies at which the mentioned electrical currents vary.

While radiation from an antenna departs from its source, recedes, and continues to exist even when electrical currents in the antenna are interrupted, there are electric and magnetic fields around an electromagnetic source that are not projected into space and disappear when the source energy goes out: they are the so-called nearby fields.

Although the dimensions of the region occupied by the near field depend on the emitting source of the field, a rough idea of its dimensions can be obtained by calculating, where is the wavelength of the emitted radiation [7].

As an example, the fields associated with electric power lines used in industry, in hospitals and in homes vary 50 times per second (50 Hz) and have a wavelength in the air of 6,000 km (6×10^6 meters).

In some countries the frequency is 60 Hz, so the wavelength in the air is 5000 km. AM radio broadcasts have a frequency close to 106 Hz (1 MHz) and an air wavelength of approximately 300 m. Microwave ovens have a frequency of 2.54×10^9 Hz and a wavelength of approximately 12 cm (1.2×10^{-1} meters).

The energy of electromagnetic radiation comes in the form of photons of energy proportional to its frequency.

When radiation is absorbed, its photons are absorbed, while when it is emitted, what is emitted is again photons.

The effect that radiation absorption can cause depends, among other things, on the energy of its photons.

It is interesting to compare the energy of the photons with the average energy of the thermal agitation movement of the particles (which occurs at the microscopic level), taking the ambient temperature as a reference. For a photon on its own to be able to produce a modification in a covalent bond or even weaker van der Waals-type stable bonds in the molecular structures of cells, its energy must significantly exceed this agitation energy. average thermal.

This last energy counts , $k_B T$ where k_B is the Boltzmann constant and T is the temperature on the absolute scale.

At room temperature this energy of thermal agitation is 4×10^{-21} Joules.

A 50 Hz photon has an energy of 3.33×10^{-32} Joules, 11 orders of magnitude less than the average energy of thermal agitation.

A 100 MHz radio frequency photon has an energy 7×10^{-26} Joules, 5 orders of magnitude greater than that of the 50 Hz photon, but still 6 orders of magnitude less than the average energy of thermal agitation.

In contrast, a far ultraviolet photon has an energy of 5×10^{-19} Joules or more, energy that is now at least two orders of magnitude greater than the average energy of thermal agitation.

Thus, at the characteristic frequencies of far ultraviolet light and X-rays (which have frequencies above 10^{15} Hz and wavelengths shorter than 100×10^{-9} meters), the photons have enough energy to break chemical bonds producing local ionization (ion formation).

For this reason, this part of the electromagnetic spectrum is called ionizing radiation.

When ionizing radiation is strong enough, it kills cells.

At lower intensities they can damage biological tissues, producing defects in genetic material and in some cases initiating a sequence of processes that leads to the appearance of malignant tumors.

At lower frequencies, such as those of visible light, infrared, microwaves, and radio frequencies, the energy of a photon is several orders of magnitude less than that required to break chemical bonds.

This part of the electromagnetic spectrum is known as non-ionizing radiation.

Since non-ionizing electromagnetic energy cannot break chemical bonds, there is no analogy between the biological effects of ionizing and non-ionizing electromagnetic energy.

This should be carefully considered when discussing the possibility that radio frequencies can cause effects such as cancer.

Indeed, in a problem involving the interaction of radio frequency waves with matter, including biological tissues, the photons taken individually do not matter, unlike what happens when studying the effects of ionizing radiation.

In the case of radio frequencies, what matters to analyze their interactions with matter is the amplitude of the electric and magnetic fields.

In the near fields the photons are emitted and absorbed by the field source (antenna or other electrical device) with equal probability per unit time, whereby the energy associated with the near field remains in the region near the source without leaving the same.

If the device or arrangement of devices emits radiation, the photons that make up the latter, once emitted, are not absorbed again but escape from the vicinity and move away from the source, propagating until they are captured by some distant object or lost in the space.

When the exposure of a biological organism to electric and magnetic fields occurs at distances smaller than the wavelength of radiation, the dominant fields are the closest ones.

Under near field conditions, as regards their modalities of interaction with tissues, electric and magnetic fields can be considered as independent entities.

However, since both are present, it is not possible in principle to rule out that they can combine their effects.

Far-field exposure differs from near-field exposure in that in the far field electric and magnetic fields are inextricably linked (electromagnetic radiation itself) when propagated from the antenna to the radio or television wave receiver.

So, somewhat schematically, the oscillation frequencies of the non-ionizing electric, magnetic, and electromagnetic fields can be subdivided into two ranges: low frequencies (say less than 100 kHz) and high frequencies (greater than 100 kHz, but less to the ionization limit).

The boundary between the two frequency ranges is blurred, but the classification is useful in studying the effects of non-ionizing electromagnetic fields on biological systems.

Comparing the amplitudes of the fields leads to another division: fields of small amplitude and fields of high amplitude.

In the case of the electric field, it is known that, if a sufficiently strong and durable field is installed in the biological tissues, an organism can be electrocuted.

On the other hand, it is now known that a weak field, under suitable conditions, can contribute to weld a bone fracture [13] [27].

The movements of ions in the electric field at low frequencies and the transfer of energy from the electromagnetic field to the tissue water molecules leading to a rise in temperature are known to cause adverse health effects.

On this there is consensus among experts. For this reason, they are the only aspects of interaction that up to now have been included in the international recommendations that limit the exposure of people to electric, magnetic, and electromagnetic fields.

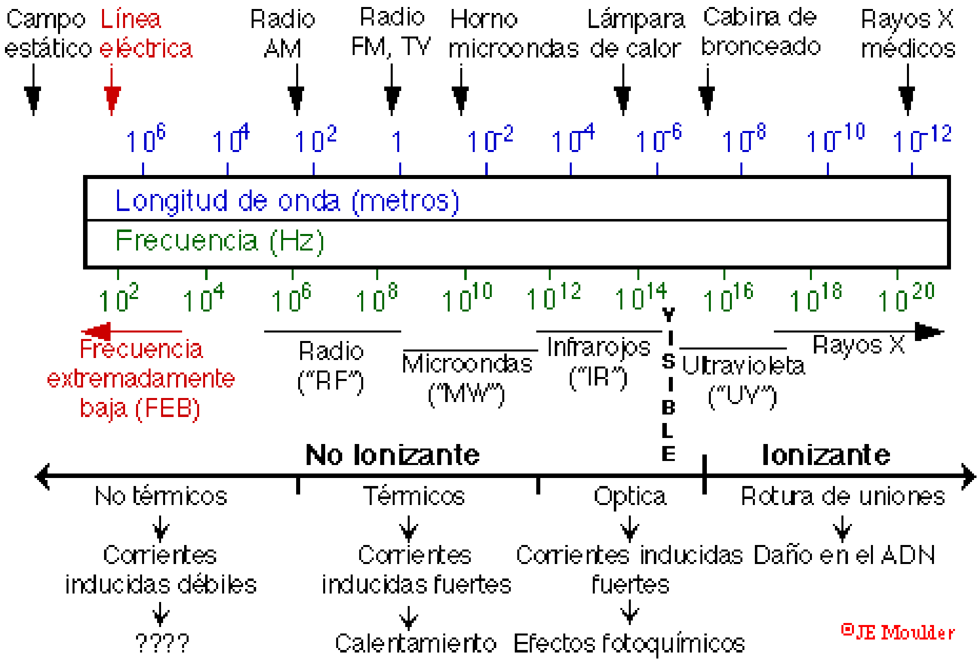
The other mechanisms that can cause biological effects and that could eventually lead to adverse effects on health, are being studied and there is not yet enough degree of agreement to introduce them into international recommendations or standards.

However, evidence is accumulating on biological effects due to weak fields, including evidence on amplitude and frequency windows.

It is to be hoped that significant developments will occur soon.

To finish this introduction, let's consider the following diagram, due to John Moulder.

It shows the regions of the spectrum and summarizes the known mechanisms of interaction with matter [15] [16]:



The ionizing region can cause direct chemical damage: X-rays, far ultraviolet radiation.

The non-ionizing region of the spectrum can be subdivided into:

(1) The part of the spectrum corresponding to optical radiation, where there can be excitations of electrons in atomic or molecular orbits (near ultraviolet, visible light and infrared light).

(2) The part of the spectrum corresponding to wavelengths generally smaller than the human body, associated with heating processes through induced currents (microwave and radio waves of relatively high frequency, say between 30 MHz and 300 GHz).

(3) The part of the spectrum where the wavelength is much greater than the body and the heating by induced currents occurs in rare occasions: radio waves of relatively low frequencies (say from 3 kHz to 30 MHz), fields associated with power (50 or 60 Hz) and static fields.

In sum, non-ionizing electromagnetic energy emissions can produce biological effects.
Many of the biological effects of near-spectrum ultraviolet radiation, visible light, and infrared radiation also depend on the energy of the photon, but are more related to electronic excitation than ionization, and do not occur. at frequencies below that of infrared light (below 3×10^{11} Hz).
Radio frequencies and microwaves can cause effects by inducing electrical currents in tissues.
These currents dissipate its electrical energy and convert it into heat.
The efficiency with which an electromagnetic emission can induce electric currents, and therefore produce heat, depends on the frequency of the emission and the size and orientation of the object being heated.

2) Geo-electric, geomagnetic, and geo-electromagnetic fields

Since humans have been exposed for eons to natural electric and magnetic fields, it is interesting to review some aspects related to the amplitudes and frequencies of these fields to compare them with the fields originated in the activities of our Technological Age.
On the surface of our planet, plants, animals, and humans encounter static magnetic induction fields B of magnitudes between 33 and 67 μT ($1\ \mu T = 10^{-6}$ T) and static electric fields E with magnitudes in an environment of 100 V / m, being able to reach 100 kV / m under a storm cloud. These static fields do not appear to be involved in biological effects.
The static geo-electric field does not seem to produce them in the absence of grounding pathways that allow the installation of significant electrical currents in the volume conductor of the tissues. The static geomagnetic field does not appear to produce biological effects in the absence of overlapping oscillating fields.
However, since geo-electric and geomagnetic fields present fluctuations associated with atmospheric storms and disturbances in the charges of the ionosphere, all biological organisms are immersed in variable fields that overlap with static fields.
In the case of the electric field, natural fluctuations of 0.01 V / m appear at frequencies up to 10 Hz. These fluctuations decrease until reaching values between 0.1 and 0.6 mV / m ($1\ mV = 10^{-3}$ V) at frequencies of 50 Hz. At higher frequencies the oscillation amplitude of the electric field, superimposed on its static value, is even smaller. It is interesting to compare these natural oscillation amplitudes at 50 Hz with the amplitudes of the oscillating electric field at that same frequency under a three-phase power transmission line, which can reach a few tens of kV / m and can light a fluorescent tube that glows without connecting wires when held in the air below the line. The amplitude ratio is from 1 to 10^7.

In the case of the geomagnetic field, the amplitudes of the oscillations at 1 Hz are 1 nT (1 nano T = 10^{-9} T), while at frequencies between 10 and 100 Hz these amplitudes are 10 pT (1 peak T = 10^{-12} T). Although during a magnetic storm the intensity can increase by 0.5 μT, this increase occurs in minutes or hours. It is also interesting to compare these oscillation amplitudes of 10 pT at 50 Hz with the more than 0.1 μT of oscillation amplitude at the same frequency, which can be measured below some power transmission lines. The amplitude ratio is from 1 to 10^4.

As these artificial electric and magnetic fields are much larger than the natural fields that oscillate at those same frequencies and that have accompanied us during our biological evolution as a species, it seems that the study of their possible effects on our organism should be of interest.

3) Electromagnetic fields and their biological effects

If the distribution of the electric field in the volume conductor formed by the tissues is known, and the electrical properties of the tissues at the frequency of the external field, as well as their density, are known, the energy absorbed per unit time and by tissue mass unit (SAR, in units of joules per second and per kilogram of body mass).

The human body is made up of tissues and organs of different electrical characteristics and arranged in a complicated geometry, so that the resulting volume conductor is heterogeneous (its electrical properties vary from region to region) and anisotropic (its electrical conductivity depends on the address where it is considered). Both the electrical conductivity σ and the relative dielectric constant ε_r depend on the type of tissue and the frequency of the external field. The conductivity σ varies between an average of 0.2 siemens per meter at 100Hz and an average of 0.9 siemens per meter at 1 GHz (the average conductivity of seawater is 5 siemens per meter, while the conductivity of copper at room temperature is 107 siemens per meter). The relative dielectric constant varies from an average of 106 to 100 Hz to an average of 100 to 1 GHz [27].

As consequence, rigorous calculation of absorbed energy can only be carried out using numerical models based on sophisticated algorithms [27]

But for estimates of orders of magnitude the simple calculation model can be used: $SAR = \frac{\sigma \cdot E_t^2}{\rho}$ where E_t is the magnitude of the electric field in the biological tissues, σ is a representative value of tissue's electrical conductivity and ρ is a representative value of tissue's mass density [26]. To estimate the field E_t in biological tissues, we must first know the external electric and magnetic fields at the site, and then estimate the electric field in the tissues because of the external fields.

As will be seen later, at relatively low frequencies (say, below 1 MHz) the external electric field penetrates very little into the tissues, while the magnetic field penetrates without difficulty.

For this reason, E_t originates fundamentally in the variation of the magnetic field flux over time.

At higher frequencies (say, to fix ideas, starting at 10 MHZ) both fields tend to penetrate and be absorbed in unison, in a process that can be described by a characteristic penetration distance (the known thickness of the film effect). of electrical engineering) that decreases with increasing frequency (at 10 MHZ it is 80 centimeters and at 1GHz about 6 centimeters) and that at sufficiently high frequencies it depends on the average curvature of the part of the body surface through the which penetrates electromagnetic radiation.

In the far field from the transmitting antenna, the electric and magnetic fields are perpendicular to each other and perpendicular to the direction of wave propagation. The intensities E of the electric field and H of the magnetic field in a radiofrequency wave that propagates in air are related by the equation $E = 377 \cdot H$ (E in volts per meter and H in amperes per meter, while 377 is given in ohms and is the impedance of vacuum, in practice (almost) equal to that in air). The electromagnetic energy S that per unit of time traverses the unit of cross-sectional area to the direction of propagation (energy flux density) is proportional to the square of the magnitude of the electric field in the air: $S = \frac{1}{377} \cdot E^2$

At very low frequencies (to fix ideas and stay within the bands supported in radio communications, say above 3 kHz and below 3 MHz, for the VLF, LF, and MF bands) the propagation of radio waves it occurs as an electromagnetic disturbance associated with the ground-air interface (surface wave). The magnitude of the field decreases as the inverse of the distance and depends on the electrical properties of the soil, and on the type of polarization (vertical or horizontal) of the electric field [17].

At higher frequencies (above 3 MHz, corresponding to the HF, VHF, UHF, and microwave radio wave bands) the ground wave does not form. But reflections can appear in conductive bodies, such as the ground plane, and hills, in the plasma of the ionosphere or if the wavelength is small enough, in buildings or even in smaller objects, and diffraction phenomena in roughness of the terrain. In MF, in addition to the surface wave, emissions are produced that reach the ionosphere and are reflected there. At some sites, the surface wave can interfere with reflection in the ionosphere. The interferences that occur because of these phenomena in the place where a person is exposed to the electromagnetic field can be destructive, decreasing the local intensity of electromagnetic radiation, but they can be constructive, increasing the intensities to something less than double that which would be measured if the interferences were not mediated. Furthermore, for fields of frequencies between 30 MHz and 100 MHz, the external oscillating field resonates with the volume conductor formed by biological tissues and the fields and local electric currents can increase significantly [13] [17] [18] [27].

The frequencies at which resonance can occur depend on the size and shape of the body.

All these considerations must be kept in mind when analyzing the effects of non-ionizing radiation, particularly microwaves and radio waves, with biological tissues, and suggest the importance of measuring local fields before making hasty decisions, which in otherwise they could be wrong.

To determine to what extent a biological organism or an electrical device is going to be able to interact with an external electromagnetic field and whether it is going to produce a resonance, the concept of electrical dimension of a body or a material system is very much more useful than geometric dimensions taken separately. The electrical dimension is defined in relation to an oscillation of a given frequency f in the material of the body or system in which the speed of propagation of the waves at that frequency is c. It should be noted that the frequency is that of the external oscillation, but the propagation speed is that of the body or system material.

If ℓ is a characteristic spatial dimension of the body or system, and if λ is the wavelength of the external oscillation in the material, the electrical dimension is defined as follows: $d(f) = \frac{\ell}{\lambda} = \frac{\ell \cdot f}{c}$

When the electrical dimension constructed from the largest linear dimension $\ell_{máx}$ of the body or system (what is known as the diameter of the region of space occupied by the body) is small with respect to the unit (to fix ideas, let's say for $\frac{\ell_{máx}}{\lambda} < 0.1$) that body or that system is considered electrically small with respect to an oscillation of the frequency considered. By increasing the oscillation frequency enough, each body or system of bodies ends up being no longer electrically small. Finally, when the reference oscillation frequency is so high (and therefore the wavelength is so small) that the smallest linear dimension of the body verifies $\frac{\ell_{máx}}{\lambda} < 0.1$, the body or system, as a whole, must be considered as electrically large.

At frequencies lower than those used by AM radio (around 10^6 Hz), electromagnetic emissions are loosely coupled with human and animal bodies and are therefore highly inefficient at inducing electrical currents and producing heat. The electric field is significantly shielded by the volume conductor formed by biological tissues (even at 1 MHz the relationship between the internal and external fields is of the order of 10^{-2} or less).

On the contrary, the magnetic field penetrates more easily, which produces the decoupling of both fields inside the tissue, even in the case in which the organism is in the field far from the emitting antenna. When the volume conductor of the tissues is interposed, a local disturbance of the electromagnetic field occurs that significantly modifies the relationship between E and H, although the wavelengths are much greater (several hundreds or thousands of meters) than the height of a person. If the exposure occurs in the near field of an antenna, the fields E and H are no longer rigidly coupled as occurs in the far zone. In all these cases of frequencies below those of AM, the biological effects that could exist would not be thermal: they would be due directly to the coupling of the electric and magnetic fields with the charges present in the molecular structure of the cells and their membranes, as well as the structures of the extracellular space in the case of multicellular organisms.

3.1) Results obtained from simplified models

Let us now consider some basic results on the fields, applicable to their interaction with biological tissues.

They are obtained from mathematical models, using the two subdivisions of the electromagnetic spectrum corresponding to non-ionizing radiation: from low-frequency radio waves to static fields, on the one hand, and microwaves and radio waves on the other.

We will begin from very simple models, which can be approached from an analytical point of view.

Despite their simplicity, they provide generally valid results within an order of magnitude, which is good to start.

3.1.1) Low frequency radio waves

In the case of low-frequency radio waves, the wavelength is very large with respect to the dimensions of a person's or an animal's organism (for example, 300 meters at a frequency of 1 MHz). Then there are no phenomena of reflection or refraction of the waves in the bodies, nor is there a very marked dispersion of the electromagnetic field. While the magnetic field penetrates the body almost without changing its value, for frequencies below 10 MHz, the electric field suffers a decrease inside biological tissues, the more important the lower the frequency.

As the wavelength is very large with respect to the maximum distance between points of the human body, an external field $E(t)$ can be assumed that is variable in time, but constant in direction and amplitude in all parts of the space close to the organism.

The body disturbs the environmental electric field in its surroundings, but the results of applying more realistic models do not change the most important conclusions obtained from the simplified model [6] [27].

Thus, we will approach the organism by means of a conductive slab transverse to the field that in air has an amplitude E_0 and oscillates with an angular frequency $\omega = 2\pi \cdot f$.

From this approximation, it is obtained that the amplitude of the oscillating field $E_{t,0}$ inside the slab is, very approximately, equal to $E_{t,0} \approx \frac{\omega \cdot \varepsilon_0}{\sigma} \cdot E_0$

For a frequency of 50 Hz the field $E_{t,0}$ is on the order of 10^{-8} times less than the field E_0 in air.

For a frequency of 1 MHz the field width decreases to less than one hundredth.

Since the magnetic permeability of tissues (except for the very small proportion of magnetosomes that may be present) is equal to that of air, while the electric field is screened by tissues, the magnetic field is not affected. Consequently, as stated in section 1 of this report when summarizing the general aspects of electromagnetic waves and their interactions with organisms, for low frequency radio waves it is expected that a certain dissociation will occur between both electric fields and magnetic inside the biological tissues of a person, and that the electrical field induced in the tissues originates fundamentally in the temporal variations of the magnetic field flow in the volume conductor.

In turn, at low frequencies (less than 100 kHz) the cell membrane shields the cytoplasm from the electric fields that may arise in the extracellular space. For a frequency of 50 Hz the field just outside the cell is 10-5 times less than the field in air, in the cell membrane it is 10^{-2} times less, and inside the cell it is 10^{-8} times less. Obviously, at this level, the electric field in the cytoplasm cannot be expected to affect the functional organelles of the cell or the DNA. However, this effect weakens as the frequency increases until at frequencies greater than 1 MHz it disappears because the membrane is short-circuited at the level of its capacitor and the only remaining screen effect is the one that the volume conductor of the tissues can produce.

3.1.2) Microwave and high frequency radio waves

At frequencies greater than 10 MHz, consideration must be given to the reflection of electromagnetic waves at the interface between air and the volume conductor of tissues, together with the skin effect and the attenuation of electric and magnetic fields as they get inside biological tissues.

Let us now consider a model consisting of a hemi-space of conductivity $\sigma(\omega)$ and dielectric permeability $\varepsilon(\omega)=\varepsilon_0\cdot\varepsilon_r(\omega)$, both dependent on frequency $\omega=2\pi\cdot f$. The other hemi-space is occupied by air.

Suppose that a plane wave, corresponding to the far field of an antenna, of angular frequency $\omega=2\pi\cdot f$ falls from the air perpendicular to the interface. Let us suppose that its electric field has an amplitude E_0 (therefore the corresponding magnetic field has amplitude $H_0=\frac{1}{377}\cdot E_0$).

Then the amplitude of the wave transmitted to the hemi-space that represents the tissues is given by the equation:

$$E_{t,0}=\frac{2\cdot E_0}{1+\sqrt{\varepsilon_r(\omega)}}$$

If a z axis perpendicular to the interface (located at z = 0), the amplitude of the electric field attenuates exponentially according to the relationship [18]:

$$E_t\left(t,z;\omega\right)=E_{t,0}\,e^{-\frac{z}{\delta}}\cos\left(\omega t-\beta' z+\phi\right)$$

In this equation $\beta'=\frac{2\pi}{\lambda'}$ it is the so-called number of waves corresponding to the new wavelength λ' in the tissues, less than the wavelength λ in the air because the speed of propagation of the wave is lower than in the air.

The phase angle φ is found from the analysis of the reflection and the transmission of the wave at the interface, and this phase angle is different in the case of the magnetic field: while in the air both fields pulsed in unison, in the volume conductor pulses out of phase with each other.

The characteristic distance δ of the exponential attenuation of the field with the penetration depth z (called the thickness of the skin effect) verifies:

$$\delta(\omega)=\frac{1}{\omega\cdot\left[\frac{\varepsilon\cdot\mu}{2}\cdot\left(\sqrt{1+\left(\frac{\sigma}{\omega\cdot\varepsilon}\right)^2}-1\right)\right]^{\frac{1}{2}}}$$

For situations encountered in practice when analyzing the interactions of biological tissues with radio waves and microwaves: $0.1<\frac{\sigma}{\omega\cdot\varepsilon}<10$ [27].

For this reason, the assumption $\frac{\sigma}{\omega \cdot \varepsilon}$ much greater than 1 is not generally applicable and, consequently, the usual approach in electrical engineering can be made:

$$\delta(\omega) \approx \frac{1}{\left[\frac{\omega \cdot \mu \cdot \sigma}{2}\right]^{\frac{1}{2}}}$$

For a frequency of 10 MHz, $\delta(\omega)$ is equal to 80 centimeters. At the frequencies generally used in cell phones $\delta(\omega)$ is approximately 7 centimeters.

Once a formula for the electric field has been determined, the energy absorbed per unit time and per unit mass can be found as a function of the depth to which the wave has penetrated:

$$SAR(t, z; \omega) = \frac{\sigma \cdot E_t^{2}(t, z; \omega)}{\rho}$$

Averaging over a period of oscillation results:

$$SAR(t, z; \omega) = \frac{\sigma \cdot E_{t,0}^{\;2}}{2 \cdot \rho} \cdot e^{-\frac{2 \cdot z}{\delta}}$$

This formula gives an idea of how the energy of the wave is deposited as it advances towards the interior of the medium in which it propagates.

The formula for estimating the thickness $\delta(\omega)$ of the skin effect can be applied when the interface between the air and the volume conductor is flat, or if it is not, when its radii of curvature are very large with respect to $\delta(\omega)$.
If $\delta(\omega)$ is of the same order of magnitude as the radii of curvature presented by the surface of the volume conductor in the region in which the electromagnetic radiation falls, the effective thickness $\delta_e(\omega)$ of the effect depends on the average curvature C of the surface.

The following approximate formula allows us to estimate this dependency [35]:

$$\delta_e(\omega) = \frac{1}{1 + C \cdot \delta(\omega)}$$

This formula was obtained in the context of the heat treatment of metal parts by induction, but it is also applicable to the study of the depth of penetration of the electromagnetic field in an organism.
The evidence suggests [35] that it is reasonably accurate for an absolute value of $C \cdot \delta$ less than 0.3. It could be extended to account for the anisotropy and heterogeneity of the tissue volume conductor.

At points where the surface is concave, the mean curvature C is negative, and then the effective thickness is greater (radiation penetrates deeper) than the skin thickness for a flat interface.
An example of this is the head of a person exposed to a microwave field, since in this case the curvatures are predominantly negative, and the radii of curvature are quite small compared to those found at the level of the chest. In turn, at the chest level, the curvatures of the body surface can vary significantly, but they are generally negative and, as we said, less than those of the head, which is why, all other conditions being equal, the thickness of the skin effect, and by therefore microwave penetration will be less in the chest than in the head.
In contrast, at points where the surface is concave and C is positive, the effective thickness $\delta_e(\omega)$ of the skin effect is less (radiation penetrates less deeply) than the thickness of the skin effect $\delta(\omega)$ for a flat surface. For an accurate estimation of the field distribution and for the calculation of the absorbed energy, detailed numerical models suitably validated through experiments should be used [14] [26].

3.2) Mechanisms of interaction of fields with biological tissues

The interaction of electromagnetic radiation with biological tissues and its effects on humans can be studied in three different and complementary ways: through epidemiological studies, through laboratory studies, and through mathematical models and computer simulation techniques. The latter are based on the current state of knowledge of the biophysics of non-ionizing radiation and on the application of electromagnetic theory of continuous media to biological tissues. This last approach is very useful, both when designing and when interpreting the results, from laboratory experiments and epidemiological field studies. It will be considered in part 6 intended to analyze the origin of the standards.

Currently the main known mechanism by which radio and microwave emissions produce biological effects is by heating (thermal effects). This heating can kill cells. If enough cells die, burns and possibly other permanent tissue damage can occur. Cells that do not die from heat gradually return to their normal state when heating ceases; There are no known permanent non-lethal damage to cells. In an animal, tissue damage and other thermally induced effects can be expected when the amount of energy absorbed by the animal significantly exceeds the amount of heat generated by normal bodily processes. These thermal effects of radio frequencies or microwaves, at the same power level as the generation of body heat in basal conditions, do not seem to represent biological risks. At lower frequencies, such as those of the electrical grid, the thermal effects are generally negligible. A very different question is whether there are non-thermal effects associated with these same power levels [15] [16] [23].

When speaking of non-thermal effects, reference is made to the mechanism of the effect. While the non-thermal effects are the result of a direct interaction between the field and the organism (for example, normal photochemical processes in organisms, such as vision in animals and photosynthesis in plants), the thermal effects they are the result of heating the molecular structures of living matter (for example, heating with microwave ovens or infrared light).

The mechanisms of the following bioelectric responses due to non-thermal effects that can be observed during exposures to external electric or magnetic fields of very high intensity (frequency dependent, direction of field polarization) are known and well established. with respect to the human body) and in intervals of variable frequency but almost always below the radio frequencies [4] [23]:

-Synaptic interactions caused by small modifications in the pre-synaptic resting potentials that are then amplified in the post-synaptic membranes and can either block or enhance the genesis of action potentials. An example of these interactions are the electrical and magnetic phosphenes (visual effects) that appear when magnetic fields or electric currents of suitable intensities and frequencies are applied to people's heads. They originate after modifications in the synaptic potentials of the receptors or neurons of the retina, without direct stimulation of the optical pathways beyond the retina, nor in the optical area of the cerebral cortex. These phosphenes are produced more frequently at frequencies close to 20 Hz: it is estimated that the minimum value of the electrical stimulus induced at the level of the retina under these conditions is 100 times less than the minimum value estimated for the local stimulus that allows generating potentials of action on the peripheral nerves.

-Excitation of peripheral nerves by supra-threshold depolarization of excitable neuron membranes. In this case the stimulus is always associated with an electric field: either the electric field produced in the tissues by the external electric field, or the electrical field induced in the tissues by the variation in time of the magnetic field that comes from of exposure to a variable external field. This is not only a problem related to power lines, low frequency radio waves or other engineering systems, but it sometimes appears in connection with magnetic resonance studies in medicine itself. The stimulating effect of an electric field, whatever its origin, is measured by the so-called activating function, originally introduced by Frank Rattay in 1986 [28]. Subsequently, it was generalized to consider both the variation of the component of the electric field parallel to the fiber, per unit length of fiber, and the variation of the local diameter of the fiber (for example, in the axon cone), the effect of the fiber curvature in a spatially uniform field and the effect of nerve endings on the electrical polarization of excitable membranes [3] [31] [32]. The genesis of an action potential is an all-or-nothing phenomenon with a characteristic threshold behavior: the threshold stimulus decreases with increasing duration and tends to a limit value (rheobase) below which excitation is not achieved [24].

-Excitation of skeletal muscle cells and myocardial cells by supra-threshold depolarization of their membranes. (In the case of the myocardium, fibrillation may appear if the induced currents exceed the corresponding threshold). In this case, an action potential is directly produced in the excitable membranes of the muscle fiber or myocardium, but the thresholds in these cases are significantly above those observed for the nerves (about 10 times). This can be explained from the parameters of the stimulus intensity-duration curves at the threshold: rheobases and time constants. It is possible to deduce analytical expressions for time constants and rheobases corresponding to both electrical stimulation of skeletal muscle and nerve fibers ([33]) and myocardium ([34]). These formulas can be extended to the case of stimulation by electric fields induced from variable environmental magnetic fields, and allow explaining the mentioned differences between nerve fibers, skeletal muscle fibers and myocardial cells [30] [36] [37].

-Electroporation (formation of large aqueous pores, non-existent under normal physiological conditions) due to abnormal hyperpolarization of cell membranes (it is reversible if hyperpolarization does not exceed 200 mV).

-Biopotential generation by magneto-hydrodynamic effects (analogous to the Hall effect) when a tissue magnetic field has a component perpendicular to the speed of an ion flow such as that which integrates the flow of blood. This effect appears in the presence of static fields and is particularly noticeable at the level of the aorta and the great arteries. When the magnetic field is strong enough, taste sensations and vertigo can appear.

The first four responses are due to the distribution of the electric field in the tissues, while the fifth is due to the magnetic field. However, there are some aspects of these accepted mechanisms that are not well known, but that could be relevant to elucidate possible effects of the fields on the human organism. What is called the response threshold is an emergent property of the system formed by the biological organism in its interaction with external fields. A critical analysis leads to replacing the concept of response threshold with that of the family of threshold states. The consequences of this substitution have been scarcely studied. See, however, the references [31] [32] [36] [37].

For several decades, work has been presented on the biological effects of non-ionizing electromagnetic emissions, the mechanisms of which are either unknown but are presumably due to non-thermal mechanisms or are purely hypothetical and currently not established.

Among the plausible non-thermal mechanisms that have been proposed to explain some human responses to exposures to low-intensity external fields, but that now cannot be considered fully accepted mechanisms by the entire scientific community, there are the following [4] [23]:

-Modification, due to electric fields external to the cell, of the propagation of solitary waves (solitons) in cell membranes, which in turn would alter the development of chemical events in the cytoplasm.

-Cooperative effects leading to a temporal-spatial integration of the induced electric fields in the tissues. These cooperative effects would occur even for external fields so weak that in the absence of this integration process they would induce tissue fields that would be well below the endogenous electric fields associated with the inevitable thermal noise of matter.

-**Stochastic resonance**, due to the nonlinearity of the biological membranes that would allow it to amplify a very weak signal aided by the electrical noise present at the membrane level.

-**Resonances of plasmons** (surface charge sheets) in biological membranes and at microwave frequencies, which would have an influence on ion transport processes, and the conformation of both the proteins integrated into the membrane and the lipid bi-layers of the membrane.

-**Rectification by cell membranes**, which would result in net ionic fluxes to or from the cell interior caused by alternating electric fields.

- **Calcium ion oscillations**, due to extremely low frequency electric fields, that could carry information to the cell.

-**Alteration in the formation of free radicals due to quantum-mechanical effects associated with the presence of a magnetic field,** with the consequent modification in the reactions involving those altered radicals.

-**Interactions mediated by magnetosomes,** ferromagnetic microparticles that are found in very small quantities in human brain tissue and being ferromagnetic, in the presence of magnetic fields at microwave frequencies, not only would they increase the absorption of electromagnetic energy but would also produce local alterations in the fields with consequences on tissue physiology.

As for the effects that are postulated without a known mechanism or at least posed in the form of a conjecture, it is very difficult to try to distinguish them from the effects associated with thermal mechanisms.
The distinction is further complicated since it is known that it is possible to produce thermal effects with low levels of absorbed energy, provided that the temperatures vary quickly enough.

An example is the phenomenon known as **microwave hearing**.
These are auditory sensations that a person experiences when their head is exposed to pulsed microwaves, such as those generated by radar.
The effect of hearing microwaves, discovered during the Second World War, turned out to be ultimately of thermal origin.
It can be observed with very low energy levels.
A very small increase in temperature (an increase of 10^{-6} ºC), which occurs very rapidly in the brain tissue, for about 10 microseconds generates by thermo-elastic expansion an acoustic wave that travels towards the cranial envelope, it is reflected and transmitted, and finally reaches the inner ear following a normal hearing process.
The perceived intensity of the acoustic effect, for a constant incident power, depends on the duration of the radar pulse. Increases and decreases in the perceived intensity are observed associated with resonances that occur in the acoustic cavity equivalent to the human head.
Since the thermal effects are due to the induced currents, and not to the electric or magnetic fields interacting directly with the tissue structures, in principle these effects could be produced by fields of very different frequencies [23] [24].

If electromagnetic resonance does occur, a local electrical field $E(t)$ significantly larger than the one appearing at that same site for oscillation frequencies outside the resonance can be installed at a certain location in the volume conductor formed by the tissues.
So, under resonance conditions, the biological structures located there interact with an oscillating field of greater amplitude, it seems more plausible to expect an energy transfer with consequences on metabolic processes and on the transfer of local and eventually global tissue signals.
When classical mechanics is applicable, the classical-mechanical analysis of the movement of charged bodies and the rotation of dipoles associated with charged bodies in electric and magnetic fields, particularly when the fields are oscillatory, is important to assess possible mechanisms of interaction of the fields with biological membranes and other structures at the cellular and sub-cellular level.

In biological tissues the translation and rotation of ions and molecules is impeded by the inertia of the particles and by viscous forces. Furthermore, in the case of particles bound by chemical bonds, movement is hampered by elastic forces that tend to restore the original position, not displaced, or not rotated.
Studying some of the possible mechanisms of interaction between fields and molecules requires the introduction of a term corresponding to a nonlinear elastic force and adding to the external oscillatory force due to the electric field an irregular function of time that describes random mechanical noises.

In general, the equation of motion for a linearly damped nonlinear oscillator can be written using a potential (a potential energy) : $U(x)$

$$m\cdot\frac{d^2x}{dt^2}=-\frac{d}{dx}U(x)-b\cdot\frac{dx}{dt}+q\cdot E(t)+m\cdot R(t)$$

In this case the elastic force is given by the expression: $F_{el}(x)=-\frac{d}{dx}U(x)$

The equilibrium positions of the free oscillator $x(t)=\bar{x}$ verify $F_{el}(\bar{x})=-\frac{d}{dx}U(\bar{x})=0$

Only the points that verify this equation can be equilibrium points of the forced oscillator.
The following expression for potential energy (elastic potential) encompasses all interesting cases to analyze possible mechanisms of interaction between weak fields and molecules: $U(x)=c\cdot\left(\frac{x^2}{2}+\alpha\cdot\frac{x^3}{6}+\beta\cdot\frac{x^4}{24}\right)$

Corresponds to a force $F_{el}(x)=-c\cdot x\cdot\left(1+\alpha\cdot x+\beta\cdot x^2\right)$

The equation of the linearly damped forced oscillator is written, in this case, after dividing both members by the mass of the particle and putting $b=m\cdot 2\cdot\zeta\cdot\omega_0$:

$$\frac{d^2x}{dt^2}=-c\cdot x\cdot\left(1+\alpha\cdot x+\beta\cdot x^2\right)-2\cdot\zeta\cdot\omega_0\cdot\frac{dx}{dt}+\frac{q}{m}\cdot E(t)+R(t)$$

Suppose the parameter c is positive and that $\alpha=0$ In that case it can be put $c\cdot\frac{1}{m}=\omega_0^2$.

Nonlinear oscillators of this type, when the amplitude of the applied field E_0 is small enough, show a resonant behavior like that of the linear oscillator, because in this case the oscillation amplitude of the displacement is small. But as the curve that represents the oscillation amplitude as a function of the frequency ω of the applied field increases, it becomes more and more asymmetric. From a critical value of E_0, a frequency interval emerges such that three possible oscillation amplitudes for the particle correspond to each frequency: the minor and major oscillation amplitudes are stable and the intermediate one is unstable. The resonance phenomena in nonlinear oscillators forced by external forces of sufficiently large amplitudes are very different from the phenomena observed in linear forced oscillators.
When the friction is weak, resonances for multiples and submultiples of a fundamental resonance frequency are observed. This may be of importance in relation to the biological effects of electromagnetic fields.

Now suppose that the parameter c is negative, $\alpha=0$ and β is negative. In that case the equilibrium position $\bar{x}=0$ is unstable, since $\frac{d^2}{dx^2}U(0)=c<0$. Two stable equilibrium positions appear, one for $\bar{x}=+\frac{1}{\sqrt{|\beta|}}$ and the other for

$\bar{x} = -\frac{1}{\sqrt{|\beta|}}$ (they are stable since for these equilibrium points $\frac{d^2}{dx^2}U\left(\bar{x} = \pm\frac{1}{\sqrt{|\beta|}}\right) = -c > 0$), separated by an unstable equilibrium position $\bar{x} = 0$.

When the term non-linear restoring force corresponds to a situation in which the particle, in the absence of external forces, has two stable equilibrium positions separated by an unstable equilibrium position, and when a noise is added to the effect of the oscillating electric field at random, a type of resonance known as stochastic nonlinear resonance may appear. This type of resonance could be important as a mechanism of action for weak fields on cells and tissues.

The translational oscillator model can also be applied to a body with magnetic moment that is in a non-homogeneous external magnetic field. When the magnitudes of the gradient of the external magnetic field and the magnetic moment of the particle are large enough, oscillations could occur. This could be the case of magnetosomes during the application of some diagnostic methods (magnetic resonance imaging) or medical treatment (transcranial magnetic stimulation).

The damped and forced harmonic oscillator is also often used as a mechanical model of the rotational motion of a molecular dipole, with angular position coordinate θ, moment of inertia I , and dipole electrical moment p :

$$I \cdot \frac{d^2\theta}{dt^2} = -I \cdot \omega_0^2 \cdot \theta - I \cdot 2 \cdot \zeta \cdot \omega_0 \cdot \frac{d\theta}{dt} + p \cdot E(t) \cdot sen\theta + I \cdot R(t)$$

The external oscillatory moment due to the electric field is given by a function of time $I \cdot R(t)$ that describes a random mechanical noise.

Now $c = I \cdot \omega_0^2$ is the constant of the restorative elastic force corresponding to a rotation, $b = I \cdot 2 \cdot \zeta \cdot \omega_0$ is the viscous coefficient of friction that opposes the rotation and $\theta = 0$ is the angular equilibrium position of the oscillator when it is abandoned to itself.

The term $p \cdot E(t) \cdot sen\theta$ is the moment, with respect to the axis of rotation, of the electrical forces produced by the external field on the dipole. Now the equation of motion is nonlinear. But if the field is oscillatory and if θ is kept small so that $sen\theta$ can be approximated by θ , and if the mechanical moment of noise is neglected, the equation of the rotating oscillator is reduced to the following linear equation:

$$\frac{d^2\theta}{dt^2} + 2 \cdot \zeta \cdot \omega_0 \cdot \frac{d\theta}{dt} + \left(\omega_0^2 - \frac{p}{I} \cdot E(t)\right) \cdot \theta = 0$$

It is noted that instead of the parameter that corresponds to the natural frequency in the case of the harmonic oscillator associated with the translation of a particle, in the case of rotation an oscillatory function appears whose frequency is the oscillation of the external field.

Then, under the right conditions, a different type of resonance known as parametric resonance may appear.

Also, in the case of rotational motion, more than one equilibrium position may exist if the elastic restoring force is nonlinear, and it may be necessary to add a random noise term to the mechanical moment due to external forces.

It is noted that, instead of the parameter that corresponds to the natural frequency in the case of the harmonic oscillator associated with the translation of a particle, in the case of rotational motion an oscillatory function $\omega_0^2 - \frac{p}{I} \cdot E(t)$ appears whose frequency is the oscillation of the external field $E(t) = E_0 \cdot \cos(\omega \cdot t)$.

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In the case of rotational motion, more than one equilibrium position may exist if the elastic restoring force is nonlinear, and it may be necessary to add a random noise term to the mechanical moment due to external forces.

The rotation oscillator model can also be applied to a body with magnetic moment that is in an external magnetic field. So, it can be applied to microscopic ferromagnetic bodies (from a biological point of view) such as magnetosomes, located in such a way that they can interact with cell membranes.
By rotating a large enough angle, these bodies could modify the ionic conduction properties of the membrane, triggering a signal sequence that could influence cellular metabolism.

Obtaining evidence to confirm or rule out some verifiable consequences of this type of conjecture is very difficult for two interrelated reasons: on the one hand, the current poor understanding of the complexity of biological systems, on the other hand the very high degree to which the research efforts required are multidisciplinary and require the integration of knowledge from various specialists.

4) Noises, fields, and contamination

Most researchers tend to think that the fields and currents associated with the normal functioning of the organism should not produce themselves nor should they act as promoters of significant damage at the level of cells, neither on their functional organelles nor on DNA. So, it seems that one should not expect harmful effects caused by the random fluctuations of the electric fields at the level of the cell membranes. The same can be expected in the case of the electrical currents that normally flow through the organism associated with the activities of the central nervous system, the neuromuscular system, and the heart, together with the electric and magnetic fields associated with these physiological currents.
If an organism is affected in any way by an external field, it appears that it could be considered a natural detector for that field. The external field would be a signal received by the detector, a signal that to be detected must overcome noise. Assuming this is so, the intensity of these noise fields provides a natural scale for comparing the intensities of intracellular or membrane-internal fields, which are due to the organism's exposure to a field of radio waves. If the intensities of these last fields are much lower or at most of the same order of magnitude as the noise fields, it could be expected that they should not produce significant effects. The spectrum of component frequencies of noise in the electric field is generally below 3 kHz in the case of electrical currents that normally flow through the body associated with the activities of the neuromuscular system and the heart, and generally by above 3 kHz in the case of thermal fluctuations at the membrane level such as the so-called Johnson noise (associated with random discharges of the membrane capacitors) or the granulation noise (associated with random fluctuations in the number of ions that cross the same channel in a membrane during the time interval in which it remains open).
With the magnetic field a curious problem arises.
In 1992, Kirschvink and others reported that the human brain contains several million ferromagnetic microparticles per gram of tissue: magnetosomes.
In 1995, Kobayashi and others discovered that contamination with magnetosomes can affect bioelectric and biomagnetic experiments carried out with tissue cultures whose cells normally do not contain magnetosomes [10].
How can this contamination occur? It is known for the time being that pre-sterilized plastic materials used in laboratory experiments with tissue cultures contain ferromagnetic particles of less than 100 nanometers, which are easily incorporated by the cells of the white series of the blood.

If we calculate the signal-to-noise ratio for one of these small magnetosomes in the earth's magnetic field, we find a value somewhat less than 1, but for a larger magnetosome, 100 micro-meters, the signal-to-noise ratio in the field terrestrial magnetic is 24.
Thus, and as far as the magnetic field is concerned, the existence of magnetosomes could be an exception due to their high signal-to-noise ratio in the Earth's magnetic field.

The magnetic fields produced by the currents that circulate in the AC transmission lines are generally 100 times smaller than the terrestrial field, but Polk, one of the greatest international experts in the interaction of electromagnetic fields with biological systems, pointed out in 1994 that a grouping of magnetosomes in a cell together with other considerations could lead to different conclusions [25].

In any case, it is an area under study, on which basic information is lacking.

There is debate and there is no consensus.

When analyzing the problem of a presumed relationship between 50 or 60 Hz fields and certain types of cancer under the conditions in which the statistical studies were performed, the fields induced both in the extracellular spaces and in the membrane and at Intracellular are several orders of magnitude below the noise fields.

Analogous results are obtained in the case of exposure to radio frequency waves. Only in a case in which the concentration of an ionic substance in the extracellular space was much higher than its concentration in the intracellular space and the membrane was permeable to that substance, could one conceive that a rectification effect at the level of the Membrane could cause a significant net current into the cells in a tissue when averaged over many cells and for a long time, even though the exogenous field is close to the noise level.

This type of mechanism was proposed in 1990 by Weaver and Anstumian ([23]) and analyzed using mathematical models in 1995 and 2000.

It is currently under study. It is not a well-established mechanism, has not been experimentally confirmed in relation to genotoxic substances, and is not generally accepted.

But, already in a purely speculative field, it could be thought that if the rectification process continued for more than 12 hours and if the chemical in question was genotoxic in addition to being a permeable ion, then some effect could be expected in some cells of a fabric subjected to this process.

In this same purely speculative terrain are attempts to justify a relationship between exposure to radiofrequency fields and cancer.

5) Comments about electromagnetic fields and cancer

There is a long-running controversy over the possibility that electric or magnetic fields of frequencies between 10^5 and 10^9 Hz cause cancer. A similar controversy arises over the possibility that fields associated with power transmission lines, in the form of 50 or 60 Hz alternating current, cause cancer or not.

While the effect, if any, is very small, the literature on the subject is considerable and includes epidemiological studies, laboratory studies, and theoretical research. The results that have been obtained are conflicting and contradictory, and there is no agreement on the mechanism or mechanisms by which a carcinogenic effect could occur.

Although little is yet known about the causes of specific cancers, the mechanisms of carcinogenesis are well enough understood that studies in cell populations and in animals can provide relevant information to determine whether an agent causes or contributes to the appearance of cancer.

Currently, research results suggest that carcinogenesis is a multi-stage process caused by a series of damages to the genetic material of cells. Thus, a multistage carcinogenesis model has been constructed. This model replaces a previous model, known as the initiation-promotion model.

The initiation-promotion model proposed that carcinogenesis was a two-stage process. The first, called the initiation phase, is characterized by specific damage at the genetic material level, due to an agent called a genotoxic agent. The second, called the promotion phase, is due to an event not directly associated with damage to the genetic material (that is, it is due to an agent that is not itself genotoxic). There is now firm evidence that this two-stage model is too simple. Many (if not all) cancers require multiple genotoxic alterations, and not all stages of cancer require a stage of promotion.

Available evidence suggests that cancer begins with damage to the cell's genetic information (DNA). The agents that cause such damage are called genotoxins. A single genetic damage is highly unlikely to cause cancer. Most likely, a certain number of genetic damages are required at specific DNA sites. Genotoxic carcinogens may not have a threshold to exert their effect: when the dose of genotoxin is decreased, the risk of inducing cancer becomes smaller, but it may never be zero.

Genotoxins can affect many types of cells and can cause more than one type of cancer. Therefore, the fact that there is evidence of the genotoxicity of an agent at any level of exposure, in any of the genotoxicity tests accepted by the scientific community, is important to evaluate its carcinogenic potential in people.

It also appears that certain non-genotoxic agents (called epigenetic agents) may contribute to the development of cancer, even if they are not capable of causing it on their own. Epigenetic agents (non-genotoxic carcinogens) indirectly affect carcinogenesis by increasing the likelihood that other agents will cause genotoxic damage, or that genotoxic damage caused by other agents will lead to cancer. For example, an epigenetic agent may inhibit the repair of potentially genotoxic damage, may affect DNA in a way that makes it more vulnerable to genotoxic agents, may allow a cell with genotoxic damage to survive, or may stimulate cell division in a cell with genotoxic damage that did not divide before.

5.1) Epidemiological studies of carcinogenic effects

Epidemiological studies have been extremely helpful in understanding the dynamics, preventing the occurrence, and mitigating the severity of infectious outbreaks. They have established beyond reasonable doubt that the probability of a smoker developing lung cancer is 30 times greater than that of a non-smoker. But when the effect is small, epidemiological studies present very serious difficulties that can invalidate them. If the probability of an effect is very small, unless the population studied is enormous, inevitable statistical fluctuations appear that introduce a very large uncertainty in the estimation of that probability. In these cases, the associations between variables are not necessarily indicating causal connections, especially when there may be unknown variables, but they are influencing the observed results and confounding the meaning of the findings. In these cases, it can be very difficult, if not impossible, to rule out the possibility that the probability of the effect is nil.

The weak associations observed may be due to these hidden variables that were not considered when designing the epidemiological study.

The following example, although it is a laboratory study on a different topic than the one in question, very well illustrates the problem of unknown variables. A study by Tucker and Schmitt, published in 1978 ([38]), summarizes five years of research into the possible perception of 60 Hz magnetic fields by humans. All work originated from the initial discovery that such an effect appears to exist. Thus, for 5 years they carried out statistical experiments, isolating subjects better and better from all sources of noise that could interfere. Finally, with a highly refined acoustic isolation chamber, none of the 200 participants in the experiment could reliably perceive whether the magnetic field was present or absent. If the researchers had been less careful, and less persistent, they would have reported a positive effect that was ultimately non-existent.

The difficulties for the proper handling of information by the public increase when positive findings receive press attention while negative findings are often ignored.

The result of epidemiological studies is summarized in a number, the relative risk, which is calculated by dividing the incidence of the effect in the group exposed to the presumed cause, by the incidence of the effect in the unexposed group.

A relative risk of one is interpreted as the effect associated with the investigated cause is non-existent.

It is generally agreed that a strong statistical association between the presumed cause and effect occurs when the relative risk is equal to or greater than 5.

In the case of lung cancer (effect), the relative risk of smokers (cause) regarding non-smokers has always been higher than 10 in epidemiological studies.

But a relative risk of less than 3 is taken as an index of a weak association between cause and effect, whereas a relative risk of less than 1.5 is considered, unless the presumed statistical association is accompanied by other supporting information, it has no statistical significance to demonstrate the association in question.
Epidemiological studies, for both radio frequencies and frequencies close to 50 Hz, show relative risks below 3 and often below 1.5 [6] [15].
Interestingly, as epidemiological studies have become more sophisticated both in the association between exposure to radio frequencies and cancer and in exposure to fields from power lines and cancer, the relative risk has not increased.

5.2) Laboratory studies on carcinogenic effects

Different laboratory studies can be performed to measure the genetic toxicity (genotoxicity) of a suspected agent. Studies can be done with professionally exposed people to see if there is damage to the genetic material of the white blood cell series.
Animal studies can be done to see if exposure to the agent causes cancer, mutations, or chromosomal damage.
Cellular studies allow investigating damage at the morphological level in the chromosomes, DNA damage, or neoplastic cell transformation.
There are currently several laboratory tests available that can be used to search for evidence of genotoxic activity.

Overall, viewed together, the experimental work on genotoxicity includes both vertebrate and invertebrate studies.
A wide range of exposures has been covered, as any evidence of genotoxicity in any system exposed to any similar type of field could be relevant to the question of carcinogenesis.
In addition to studies on genotoxic agents, experimental studies have been carried out on suspected epigenetic agents, specifically on the so-called promoters.

In a classic promotional analysis, animals are exposed to a known genotoxin, at a dose that will cause cancer in some, but not all, animals.
Another group of animals are exposed to genotoxin plus the agent to be evaluated for promoter activity.
If the agent plus genotoxin causes more cancers than genotoxin alone, then the agent is a promoter.
Some cell studies are relevant to the carcinogenic potential of the agents, but they are not classical genotoxicity or promotional tests.
For example, cellular systems have been used to analyze whether an agent increases the activity of a known genotoxin, or whether an agent inhibits the repair of DNA damage.
These cellular studies of epigenetic activity can be viewed as the equivalents of a promotion study.

The effects of epigenetic agents can be specific to each tissue and species, and there is experimental evidence that epigenetic agents present a threshold for their effects.
Therefore, in relation to its relevance for human carcinogenesis, the evidence that an agent has epigenetic activity should be carefully evaluated under actual exposure conditions.
This is important for the issue of possible cancer risk due to radiofrequency fields, since the experimental evidence, insofar as it could implicate these fields, suggests if they act, they should do so through an epigenetic mechanism and not from a genotoxic one.

Most of the agents known to be carcinogenic to humans are genotoxins.
There is no evidence to believe that the electric or magnetic fields produced in biological tissues, because of exposure to radio frequency waves or frequencies of the electrical power network, are genotoxic.

The possibility that they would act as epigenetic agents would remain open, although no mechanisms are known that could explain this possibility.
However, the role of epigenetic carcinogens in leukemia or brain tumors, which are the types of cancer most associated in certain epidemiological studies with exposure to fields associated with low-frequency radio waves, has not yet been identified. , or to frequency fields close to the frequencies of the alternating current power supply network.
The absence of mechanisms to explain the epigenetic action of the fields together with small relative risk values does not allow us to exclude the effects due to variables that remain hidden in the epidemiological studies mentioned.
The International Association for Cancer Research classifies radiofrequency fields in a group (2B: possibly carcinogens) that includes coffee, mate, and vegetables preserved in vinegar (pickles).

6) The foundations of the recommendations and standards related to the exposure of humans to radio frequency and microwave frequency electromagnetic fields

Bearing in mind all that has been said about the interactions of non-ionizing radiation with biological tissues, let us now consider the issue of recommendations and standards.
We will begin with a historical study of the modifications suffered by US standards, and then consider the limits that appear in the standards of other countries and in international standards.

The old regulations (in force in the USA until 1982) established limits to the incident power flow, putting that limit at 10 thousandths of a watt per square centimeter, for all the radio frequency and microwave bands, because it was thought that the only biological effects that occurred, they had a thermal origin that could be directly correlated with the incident power.
Furthermore, no distinction was made between the public and occupationally exposed persons.

Subsequent experimental studies confirmed that the observed effects correlated much better with the energy absorbed per unit time and mass (SAR) than with the incident power density.
For this reason, the expert committee of the American Standards National Institute (ASNI) that analyzed the situation leaned in favor of SAR as an indicator of possible biological effects due to the electromagnetic field.
Incident power density was discarded as an exposure criterion because it is not equivalent to SAR.

Although the incident power density S is a basic datum to take into account on every occasion when it is necessary to evaluate possible effects of non-ionizing radiation, the incident power density by itself is not a good indicator of possible effects. of electric and magnetic fields on the tissues of an organism.
This is because when the SAR value field produced by the same incident power density is averaged over the entire organism, the resulting average turns out to be a function of the frequency of the incident radiation.
Then, if a limitation were imposed to the maximum admissible value for the SAR, the threshold incident power density for which this limit would be reached, would vary as the oscillation frequency of the field in the environment changes: $S = S_u(f)$

For the determination of the relationship between the SAR and the incident power, the worst case in which the electric field is vertically polarized is assumed, because this maximizes the amount of energy absorbed from the same incident radiation power.
A limit of 0.4 watts per kilogram of tissue mass was established, which should not be exceeded.
To establish this limit, we worked experimentally with a population of laboratory rats.
It was found that for a SAR averaged over the whole body and exceeding 4 watts per kilogram, alterations were ob-

served in the behavior of rats when faced with complex tasks, although it was not possible to determine if the effect was of thermal or other origin.

From a physiological point of view, 4 watts per kilogram is used when performing a moderate activity, such as cleaning a house or driving a car, and is always within the limits to which the normal mechanisms of success are applied. thermoregulation.
Despite everything, the expert committee applied an arbitrary safety factor of 0.1 and established that the limit for the average SAR for the entire human body that must not be exceeded is 0.4 watts per kilogram.
This decision, the basis of the ANSI standard of 1882, is still controversial today.

They then established a threshold curve that relates the incident average power density to the frequency of the electromagnetic field so that, in every conceivable case, the average SAR over the entire body does not exceed 0.4 watts per kilogram of body mass.
It is averaged over the entire body and over a fixed time interval.
The averaging times will be considered later.

See the following Figure 1.

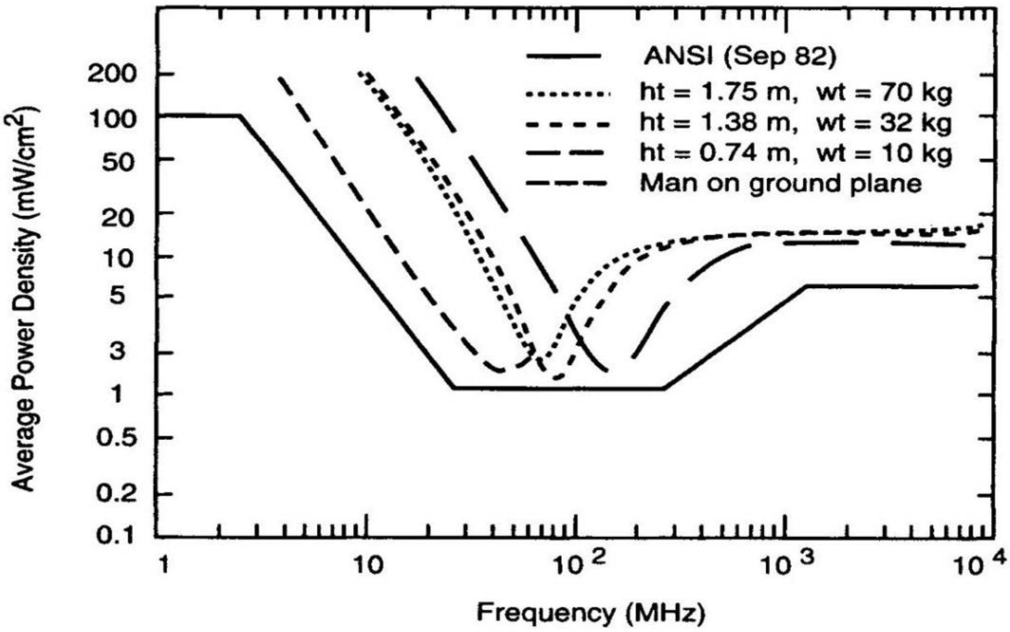

Figure 1

In the frequency range between 30 and 100 MHz, where resonances occur between electromagnetic waves and the volume conductor of the human body, the ANSI curve presents a minimum horizontal plateau corresponding to an incident power density 1 milli watt per square centimeter.
This ensures that the threshold curves for 0.4 watts per kilogram for both children and adults of different heights and body weights are all well above the single curve set by the standard.

The incident power versus frequency curves, corresponding to each human body for the SAR taken as the threshold not to be exceeded, once they are away from the minimum resonance that corresponds to that body according to its size and shape, increase inversely proportional to the frequency when the latter decreases approaching zero.
To avoid other problems, such as induced shocks or sparks to the body in high intensity fields, ANSI experts intro-

duced an additional restriction: below 3 MHz the incident power density must not exceed 100 milliwatts per square centimeter.

Above the resonance frequency the power densities corresponding to the threshold curves for each body increase with frequency and then, at a higher frequency, depending on body size and shape, stabilize.

The curve proposed by ANSI presents a plateau starting at 1 GHz located at a power density of 5 milliwatts per square centimeter.

To apply the threshold curve, it is necessary to measure or calculate the power density at the corresponding frequency, due to a certain emitter, which would affect a person in a certain place.

Before 1983, no distinction was made between the public and workers occupationally exposed to non-ionizing radiation, unlike what has been practically done since the beginning of exposure to ionizing radiation.

As of that year, some public health departments began to make the distinction, which in 1991 ended up being collected by experts from the Institute of Electrical and Electronic Engineering (IEEE, a professional society originated in the USA, but worldwide in scope) in the IEEE-ANSI standard.

In particular, the Massachusetts State Department of Public Health established that the admissible exposure for the public should be one fifth of the admissible exposure for occupationally exposed workers.

For the latter, the curve in figure 1 was maintained, while for the public an incident power versus frequency curve was applied, which corresponds to a SAR averaged over the whole body of 0.08 watts per kilogram.

The rationale for this factor 0.2 is based on the following considerations. The worst case for the public is one in which they spend the entirety of a week in the vicinity of a source of radiation of radio waves or micro-waves, suffering an exposure equivalent to that of an occupationally exposed worker. This chronically exposed public remains 168 hours per week at the same level of exposure as a worker only suffers from this exposure for a maximum of a 40-hour work week. Dividing 40 by 168 and rounding the result down gives the mentioned factor 0.2.

Another modification introduced after separating the public from the occupationally exposed workers was the determination of the time interval over which the incident power should be averaged to apply the threshold curve corresponding to each case: 30 minutes for the public case and 6 minutes in the case of occupationally exposed workers.

All these modifications were admitted in 1986 by the National Council of Radioprotection (NCRP) of the USA.

The committee of experts that prepared the IEEE-ANSI standard of 1991 introduced very significant modifications with respect to the ANSI standard of 1982, namely:

-The advisability of making a distinction between the public and occupationally exposed workers (together with the differential limits established by the State of Massachusetts that we have just exposed), proposing from this premise a distinction, taken from radiation protection for ionizing radiation, between a controlled environment and an uncontrolled environment.

A controlled environment refers to places where the people who are there are fully aware that they can suffer or are exposed to non-ionizing radiation, either for work reasons or for accidental transit of people through areas in which the exposure can be found between the environmental limits established for a controlled environment and an uncontrolled one.

An uncontrolled environment refers to places where people are unaware or at least have no control over the exposure to which they could be exposed, such as in homes or workplaces not related to sources of the electromagnetic field. .

-The partition of the conventional threshold curve for incident power density as a function of frequency into two curves: one for the wave's electric field and the other for its magnetic field.

Figure 2 below illustrates these modifications.

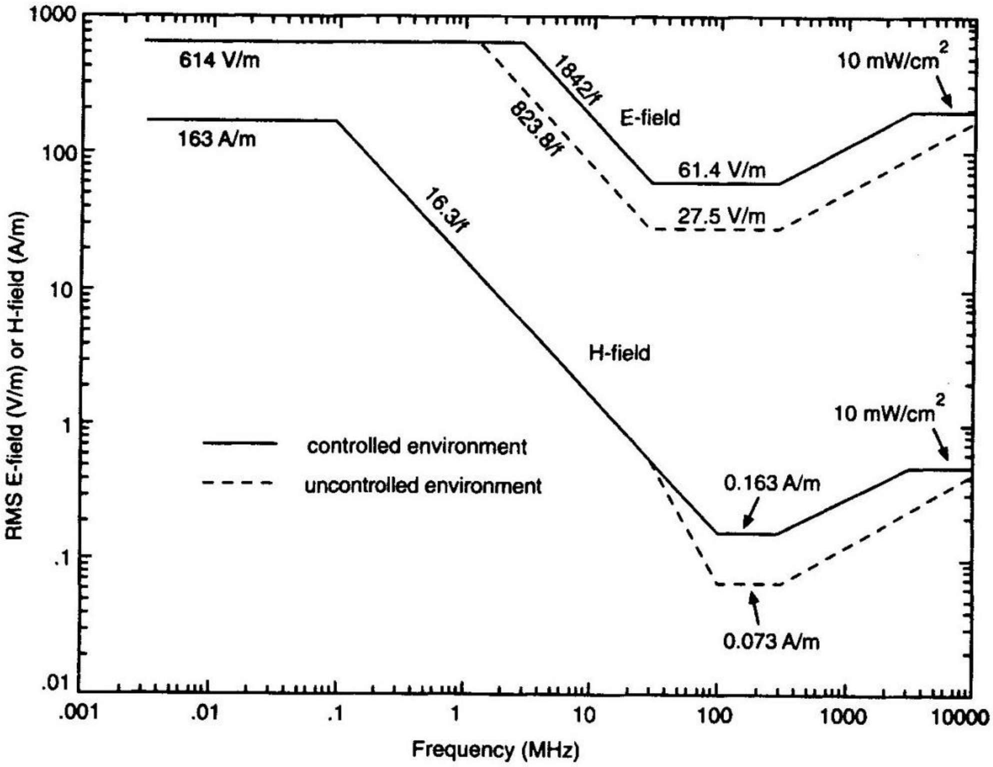

Figure 2

In the frequency range where resonances occur for different sizes and shapes of human bodies, the experts decided to apply an additional safety factor in the case of uncontrolled environments (dotted lines for field thresholds). electrical and for magnetic field thresholds in figure 2).

Experiments show that the electric field is more easily coupled with living matter to produce different biological effects, compared to the magnetic field of the same incident wave. For this reason, it was decided to start from the threshold curve for the power density $S = S_u(f)$ of figure 1, and from it calculate a threshold electric field expressed in volts per meter (upper continuous line in figure 2): $E_u = E_u(f) = 173 \cdot \sqrt{S_u(f)}$

The thresholds for magnetic field, expressed in amps per meter (lower continuous line in figure 2) were selected to allow, below 100 MHz, greater exposures than in the case of the electric field.

That is, below that frequency the thresholds for $H = \frac{E}{377}$ are taken less than the threshold $H_u(f) = \frac{\sqrt{S_u(f)}}{173}$, which would be the value of the magnetic field amplitude corresponding to the threshold of the electric field:

$$E_u = E_u(f) = 173 \cdot \sqrt{S_u(f)}$$

All this assuming that the exposed person is in the far field with respect to the transmitting antenna.

In other rules and regulations, the magnetic field is expressed through magnetic induction or magnetic flux density $B = \mu \cdot H$

Both in air and in biological tissues, magnetic permeability μ can be equal to that of vacuum: $\mu_0 = 4\pi \times 10^{-7}$ Henry per meter.
The field is measured in Tesla. To switch to micro-tesla (millionths of a tesla) the magnetic field data in Figure 2 must be multiplied by 1,257. From a practical point of view, both ways of expressing the magnetic field are equivalent.

As in the previous 1982 standard, the 1991 IEEE-ANSI standard introduces a uniform limitation to frequencies below a limit frequency to avoid induced currents and discharges that could cause damage. In addition, a uniform limitation in incident power density of 10 milli watts per square centimeter is introduced at frequencies above 15 GHz, applicable in both controlled and uncontrolled environments.
Although these restrictions ensure a limitation of the SAR to the whole body below 0.4 watts per kilogram at any frequency, it is known that different regions of the body could have SAR values higher or lower than this threshold.
For this reason, restrictions are relaxed in the case of the extremities (especially feet and hands) and a little less in a small portion of any other part of the body, differentially depending on whether it is a controlled or uncontrolled environment.
For feet and hands, a SAR of 20 watts per kilogram averaged over 10 grams of any tissue from a person in a controlled environment and 4 watts per kilogram averaged over the same mass of tissue for a person in an uncontrolled environment is allowed.
For the rest of the body, it is admitted that in a mass of only one gram of body tissue a SAR of 8 watts per kilogram can be absorbed.
For frequencies below 15 MHz an averaging time of 6 minutes is adopted.
Above that frequency the averaging time is lowered to 10 seconds in a controlled environment.
For pulsed fields, special restrictions are introduced that limit the peak values of the exposure to oscillating fields.

One of the most frequent and most important situations of exposure to pulsed fields occurs in medical diagnostic procedures based on images obtained by magnetic resonance imaging.

Like the standards that preceded it, the 1991 IEEE-ANSI standard imposes restrictions on the maximum allowable intensity for fields at frequencies below the lower limit of the resonance range. This is done both to avoid shock through the body and electrical shocks, and to avoid induced currents that could cause unwanted stimulating effects on the nervous system, skeletal muscle, or myocardium.

Figure 3 shows what happens when the body of a standing person interacts with an environmental electric field, vertically polarized and oscillating at a relatively low frequency. Numerical methods of calculating the distribution of fields in the organism, such as those outlined in Figures 3 and 4 can be studied in reference [13] and in volume 1 of reference [27].
The volume conductor of the tissues is seen to disturb the field lines that tend to concentrate in the adjacencies of the body, impacting vertically on the body surface.
The direction of the field lines is reversed every half cycle of oscillation.

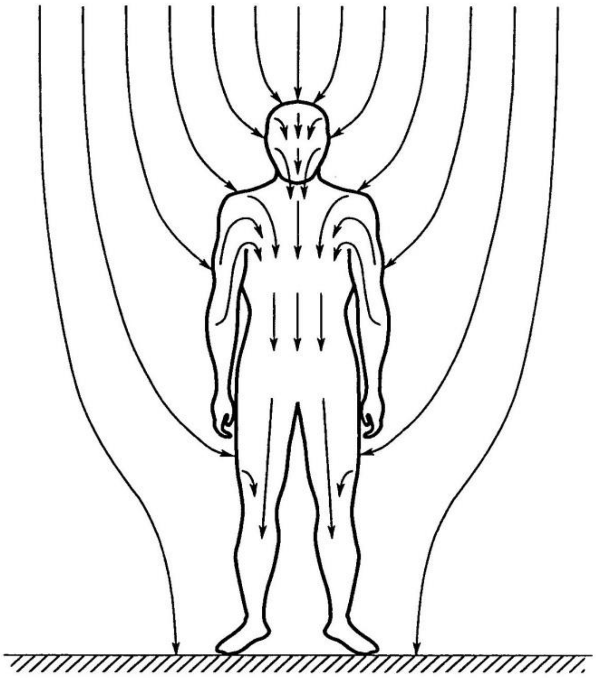

Figure 3 (modified from J. Patrick Reilly, 1998)

Although the electric field outside is thus increased, when passing from the outside to the inside of the body it suffers a strong shielding, as seen in Figure 3.

The purpose of the 614 volts per meter limit imposed on the amplitude of the field at frequencies less than 3 MHz (see figure 2) is to avoid discharges to earth through the volume conductor formed by body tissues.
Under these conditions, direct stimulation of nerve or muscle fibers or synaptic interaction, considered in part 1 of this report, does not occur.

The magnetic field is not screened at relatively low frequencies, so an oscillating field induces electric fields and currents in the volume conductor of the tissues.
The upper part of Figure 4 shows what happens in two situations of interest: when a person is standing in a vertical magnetic induction field, and when he is standing in a horizontal magnetic induction field.

The figure shows the lines of the field and the induced electric currents, all closed on themselves.
In general, the greater the length of the field line, the greater the induced electric fields.
As it appears from figure 4, the greatest amplitudes of the electric field induced by the variation of the magnetic flux take place near the surface of the body.

All other conditions being equal, current lines induced by a frontal magnetic field (left-hand side of Figure 4) are going to be associated with fields and densities of electric current in tissues near the body surface that are larger than the fields and current densities associated with current lines induced by a longitudinal magnetic field (left part of figure 4).

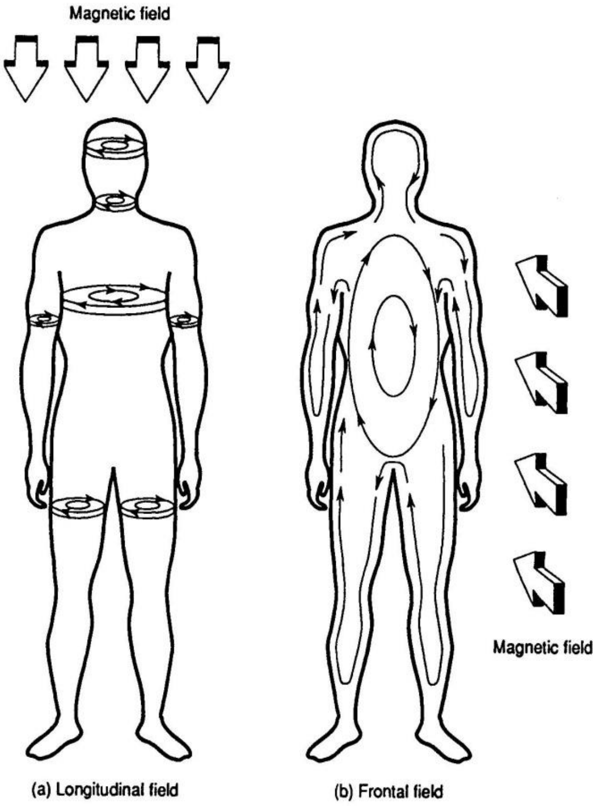

Figure 4 (modified from J. Patrick Reilly, 1998)

If only the threshold SAR criterion were used, no additional limitations should be imposed on the amplitude of the electric field at low frequencies in body tissues.

To see this as simply as possible, consider the energy absorbed per unit time and mass $SAR = \frac{\sigma \cdot {E_t}^2}{\rho}$ averaged over a period of field oscillation. Then, using the results obtained from the simple slab model for the tissues in a low frequency field, the following expression for the averaged SAR results: $SAR = \frac{\sigma \cdot \omega^2 \cdot {\varepsilon_0}^2 \cdot {E_0}^2}{2 \cdot \rho}$

From this relationship it follows that if the SAR is to be kept constant, for example at its threshold value of 0.4 watts per kilogram of tissue mass, or at 0.08 watts per kilogram of tissues, then the product of the amplitude of the oscillating field by its frequency must be constant: $f \cdot E \approx \frac{\sqrt{2 \cdot \frac{\rho}{\sigma} \cdot (SAR)_{umbral}}}{2\pi \cdot \varepsilon_0}$

This reciprocity relationship $E \propto \frac{1}{f}$ can be seen in Figure 2 for frequencies below the lower limit of resonances and above the upper limit of the frequency range for which a constant threshold value of 614 volts per meter is set for the electric field of the electromagnetic wave or disturbance.

The restriction to magnetic fields less than 163 amps per meter (0.205 thousandths of tesla) that the standard imposes for oscillations below 100 kHz (see figure 2), ensures that the stimulation of nerve fibers and the other well-established effects of Interaction of non-ionizing radiation at those frequencies, considered in Part 1 of this report, does not occur. Even in the worst case conceivable, the thresholds for these non-thermal effects are several orders of magnitude above the restriction imposed by the standard.

In addition to restrictions on admissible environmental electric and magnetic fields, the IEEE-ANSI standard imposes limitations on electrical currents that could be induced in different regions of the tissue volume conductor (root mean square values of alternating currents in milliamps and the corresponding -te frequencies in MHz with an averaging time of 1 second) for controlled and uncontrolled environments, with people standing in two situations: with the soles of the feet touching an energized metal object, on the one hand, and not touching it by the other.

These additional limitations were introduced because the limits on the environmental fields may be not enough to avoid the perception of electric current when contacting an energized conductor. But if contact with an energized conductor occurs through the hands and in a small person, these limitations may not be enough to avoid painful sensations.

Aside from the IEEE-ANSI standards that we consider so far, numerous regulations and standards have been developed in different countries, for both civil and military use. They have presented significant differences between them, something that has not happened in the case of ionizing radiation, on which a greater consensus has always developed.

In 1992, the International Commission for the Protection of Non-Ionizing Radiations (ICNIRP) was established as a separate entity that is a member of the International Association for the Protection of Radiation (IRPA). This commission has been publishing recommendations on the interaction of electromagnetic fields with biological tissues in conjunction with the World Health Organization.

These recommendations and national standards, such as the British and the Dutch, emphasize the resonance phenomenon between 30 and 100 MHz and establish limits that differ by a factor of 2 with respect to what is established in the ANSI standard. IEEE 1991.

Recommendations and standards differ much more from each other at frequencies below 100 kHz and above 10 kHz. Thus, the limits for the intensity of the electric field in this frequency range are, in volts per meter: 1500 in Germany, 1000 in the United Kingdom, 614 in the USA, 614 according to the International Commission for the Protection of Radiation No Ionizing, 280 in Canada, 87 in the Netherlands, and 25 in the Russian Federation. The limits for the magnetic field in the same frequency range are, in amps per meter: 350 in Germany, 163 in the USA, 64 in the United Kingdom, 64 according to the International Commission for the Protection of Non-Ionizing Radiations, 4 in the Netherlands and 1.8 in Canada.

Figure 5 shows the limits on the power flux-density of high frequency electromagnetic radiation [12].

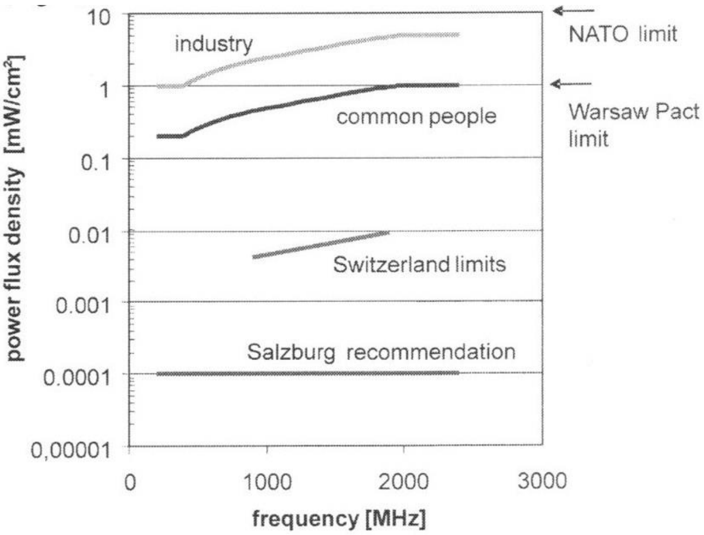

Figure 5

For the general population, indicated by “common people” in the figure, the limit coincides with that established for the military in the Warsaw Pact, at the time of the Soviet Union [12].
For the NATO military the limit was set at a level 10 times higher than that of the Warsaw Pact.
The Swiss limit has been decreasing. It is one hundredth of the German one. But they apply it only in so-called "sensitive areas", such as schools and kindergartens. Of course, once children leave sensitive areas, they can experience significantly higher exposures.
Finally, the limit established at the 2004 Salzburg meeting is 10,000 times lower than the German one.

A review of the ICINRP standard of the International Commission for the Protection of Non-Ionizing Radiation, a standard that ranges from 0 Hz to 300 GHz, can be found in reference [39]. A revision of the international standard on exposure to electromagnetic fields will be available in 2016. Regarding the latter, it is suggested to consult the website of the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

In the ICNIRP manual on dialogue on the risks of electromagnetic fields in health (reference [9]), you can find many useful recommendations for managers and politicians who must deal with this issue.

Two issues that often concern people and generate complaints to municipal and national authorities are the possible health effects of high-voltage 50 or 60 Hz power transmission lines and cell phones that they operate at frequencies between 900 and 1800 MHz.

Let's consider high-voltage lines first.
While the electric field is highly distorted by a person's body, the magnetic field is not: it passes through it easily and produces a variable magnetic flux in the volume conductor of the tissues.
Taking for the amplitude of the oscillating magnetic induction a high (conservative) value of 1 mT, an amplitude of the density of induced electrical current in tissues of 3 mA / m^2 can be estimated.
This value can be compared with the 100 mA / m^2 that is generated in the brain and the 500 mA / m^2 that are generated in the human heart under physiological conditions.

Since the current density is proportional to the oscillating magnetic field, and since the amplitudes of said field below a high-voltage transmission line are less than 20 µT (it is 50 times less than the value assumed for the calculation) It can be concluded that the induced currents are much lower than the physiological currents.
The corresponding calculation for the electric field leads to the same conclusion [27].

Now consider cell phones.
Regarding the interaction of the electromagnetic field with the tissues, the effort of the producers has concentrated on reducing as much as possible the power that the cell phone's antenna handles.
If the antenna transmits information with a power of 0.1 W and that during operation people keep the phone very close to their heads, a SAR of the order of 1 watt / kg of tissue can be estimated (averaging over 10 g of tissue).
As this value exceeds the threshold of 0.4 watt / kg tissue, if this threshold is accepted it seems prudent not to abuse the use of a cell phone with this antenna power without an electroacoustic intermediary [14] [27].

As studied in the reference [29], perception and subsequent response in relation to environmental problems in general, and specifically to the problem studied in this report, are related to cognitive, emotional, sociocultural, and even ideological characteristics.

A proper approach requires recourse to concepts (summarized in the German terms Umwelt, Mitwelt, Eigen-welt) and tools of environmental psychology, social psychology, and psychology that emphasize the individual.

Environmental psychology studies the two-way and reciprocal interactions between people and their socio-environments, focusing on the specific and changing environment, contemporary to the human species (Umwelt).

In this study of interactions between people and their environments, social psychology contributes the study of the meeting situation between the individual and society, focusing on the world of interactions with beings of the same species (Mitwelt).

And psychology as such puts its emphasis on the study of the world of each person (Eigenwelt) who lives in society and shares an environment with others.

Changes in one of these three worlds, generates modifications in the other worlds.

Formal education and information provided by the media can help clarify some of these changes.

The media frequently report on events associated with climate change and chemical or biological contamination of water, air, or soil.

Less frequently they pose problems related to radioactive waste or the effects of electric, magnetic, and electromagnetic fields on health.

For its part, formal education generally does not include among the topics addressed a comprehensive approach to environmental education, it does not usually include a reasonably complete and updated approach to the topic of this report: the relationship between electric, magnetic, and electromagnetic systems and the health of individuals and populations.

This lack of information contributes to the appearance of fears, often unfounded.

7) Conclusions

Beyond the specific details of any regulation, it should be noted:

(a) The origins of whole-body averaged SAR limits (0.4 and 0.08 watts per kilogram) and how to establish the difference between those limits for controlled and uncontrolled environments, and their relationship to human health .

(b) The absence of consensus on the limits for environmental fields at low frequencies.

The 0.4 watts per kilogram established by dividing a SAR value of 4 watts per kilogram by 10, obtained from experiments with rats showing impediments to carrying out complex tasks, and the partition initiated in 1981 by the Department of Public Health of the State of Massachusetts in controlled and uncontrolled environments, have been controversial and continue to be so.

Subsequent studies on the setting of thresholds of power absorbed by tissues have not produced conclusive results in relation with the possible thermal origin of the mechanisms associated with most physiological effects.

The distinction, in relation to the thresholds to be applied, incorporated in the norms imitating the common practice in the case of ionizing radiation, between the public and occupationally exposed workers, has been repeatedly questioned.

In 2001, at a meeting of the IEEE International Electromagnetic Safety Committee (ICES), known colloquially as SCC-28, the elimination of the distinction between the public and occupationally exposed workers was proposed, applying in all cases a SAR of 0.4 watts per kilogram [1].

It is clear how confusing the problem of establishing exposure limits is. One of the reasons for this situation is the lack of firm and admitted evidence by consensus [13] [27].

Apparently, a good part of the difficulties in establishing the interaction mechanisms between fields and tissues, and therefore the difficulty in investigating biological and health effects, are related to a scientific paradigm in cellular and molecular biology that is becoming inadequate. References [11] [13] [19] [20] [21] [22] can be found on the background and status of the subject.

Possibly another reason is the non-disclosure of certain knowledge, protected by secrecy, both military and that of the State security organs. It is interesting how low the limits were in the time of the former USSR.

Formal education and the information provided by the media should provide elements of judgment to citizens, to collaborate an adequate understanding of the current situation on the subjects considered in the present report.
It is important not to lose sight of the fact that the perception and subsequent response of the population in relation to environmental problems in general, and the problem studied in this report, are related to cognitive, emotional, socio-cultural, and even ideological traits.

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